Paleolandscape reconstruction at the lake-dwelling site of Dispilio, Northwestern Greece: A geoarchaeological approach

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4. Research design and data collection

4.1. Introduction

This project has a twofold methodology based on two scales of analysis; a) the large-scale sedimentological analysis and b) the microstratigraphic high-resolution analysis of the archaeological site of Dispilio. Two standard methods of analysis are therefore implemented: The first basic analytical tool is sedimentology, which includes grain size analysis (granulometry) and organic/carbonate content analysis (TGA) and the second is soil micromorphology, through which it is possible to study site formation processes, paleo-environmental changes and trace human activities with exceptional resolution. The sedimentological and microstratigraphic data are combined to identify facies and microfacies, presented in stratigraphic cross sections and profile drawings. Each recognizable package of sediment with particle size, color, structure and inclusions comprises a facies, which forms under certain conditions of sedimentation, reflecting a particular process or environment (Feibel, 2001: 129). To correlate the sedimentological and micromorphological results, a chronological framework is constructed based on ^{14}C AMS dating. Finally, all the above data are integrated and visualized in 3D reconstruction models.

4.2. Materials and Methods

Sampling for sedimentological and micromorphological analysis has been carried out in the site of Dispilio and along the lakeshore, at the east of the site (figs. 4.1 and 4.2), where the natural stratigraphic sequence could be traced. The west side was not easily accessible for coring. Furthermore, and as it is thought that part of the site is now submerged, drilling has been conducted at the north of the reed beds, in the lake (fig. 4.1). The sampling at this location has been very demanding, as the reed beds restrict the access from the shore. A boat was used to reach the spot from the north; however, the cores did not reveal any anthropogenic signal. Sampling in the shallow waters of the lake includes cores DMG33, 34, 35 (fig. 4.2).

For this study, topographic maps of 1: 5,000 and 1: 50,000 scales were used. The maps were provided by the Geographic Service of Greek Army and are using the HATT projection coordinate system.

4.2.1. Coring equipment and sampling strategy

Drilling has been performed using a Cobra Vibro corer, provided by the Geography Department of Harokopio University, in Athens. This type of equipment can penetrate in 5 meters' depth in an exchangeable open gouge, or alternatively in a solid gouge with the use of semitransparent liners. The liners were cut in halves in the laboratory along their length; one half is sub-sampled for thin section preparation and the second is used for sedimentological analysis and dating. For this project, liners were used for sampling off the site, at the lake. At the mound, the presence of a calcitic crust at the upper layers prevented the solid gouge from penetrating, without disturbing the sedimentological structure. For this purpose, the open gouge was used at the upper 1meter. In greater depths, the solid gouge with the liners was used selectively: In total 34 cores were drilled (fig. 4.2 includes cores DMG1, DMG2, DMG4 and DMG5 from Karkanas *et al.*, 2011). Liners were used for DMG14, DMG15, DMG16, DMG17, DMG18 and DMG39 processed for micromorphological analysis. To examine the stratigraphic sequence right before and during the habitation of the settlement, sampling in the site aimed at covering the anthropogenic deposits and reach the lake bottom in the maximum depth. The boreholes' depth, therefore, does not exceed 3m (exception DMG17 reaching 4m); the distance in between the samples is averagely 10 m.

The off-site sampling, on the other hand, would reach greater depths, so as to examine the evolution of the lacustrine deposits, without the input of anthropogenic activity (fig.4.1). The boreholes depth ranges from 1m to 5m. 1m cores were used locally (DMG23-DMG29), to reveal the extent of anthropogenic deposits reached within 0.5m depth. The distance between the cores, was adapted during sampling process and was dependent on the preliminary macroscopic results. Therefore, sampling is denser at the eastern part of the lakeshore close to Giole stream, where anthropogenic deposits have been located.

The exact coordinates and absolute depth of the core points were measured with a total station. The coordinates were implemented on Google earth application to produce the off-site map (fig.4.1); absolute depth has been used for the cross-section reconstructions. Both parameters have been used in Rockworks software for the reconstruction of cross-sections and 3D models creating the surface and facies relief (fig. 4.2).

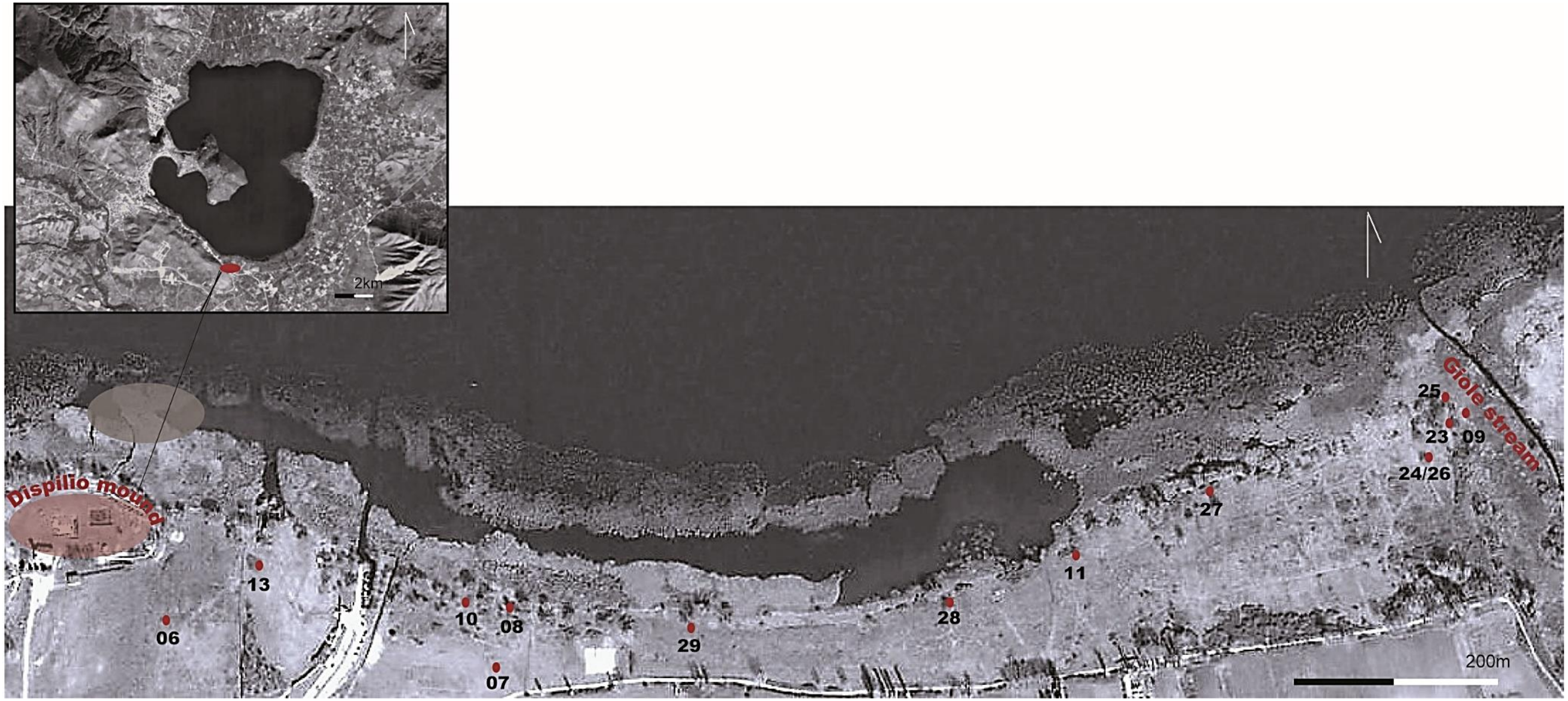

Figure 4.1: map showing The archaeological site of Dispilio in red to the west and the giole stream to the east. the off-site boreholes are indicated in red dots. The location of the site at the south shore of the lake in northwestern Greece is seen at the upper left figures. The boreholes in the archaeological site are seen in figure 4.2. The grey circle at the north of the site indicates the area of sampling by boat referred to in the text

4.2.2. Micromorphology tools and materials-the sampling strategy

For micromorphology sampling several methods are available in the literature (e.g. Kubiena boxes, paper wrapping, tubes etc.) (Kubiena, 1970) and are differing in relation to the structure and composition of the material sampled (Goldberg and Macphail, 2006: 330-2). For this project a combination of two methods has been used. Blocks of 8X5 with a length of 20 to 45 cm were cut on the profile in most cases and were further covered with plaster of Paris. The number and the thickness of the microfacies dictated the size of the samples. In few cases of fine layers, Kubiena boxes were preferred (KS3, KS4, KS8, KS11, KS22-KS26).

In the site, the east sector (fig. 4.2) is used as a reference and is therefore densely sampled, being the most extensively excavated sector (excavation has reached a maximum depth of approximately 2m, in a surface of 30x20m). Sampling would be concentrated in the lower facies, which demonstrate a high degree of variability, whereas upper facies have a relative homogeneity. The off- site sampling was conducted at the exposed profile of the Giole stream, where anthropogenic deposits have been located (fig. 4.1). In total 25 blocks for thin section processing have been extracted from the profiles of the mound and the Giole stream. Micromorphology samples were further subtracted from the cores, where liners were used (as described above). DMG14, DMG15, DMG17, DMG18 and DMG39 (fig. 4.2) were processed for micromorphological analysis in the site; at the lake shore DMG06, DMG09, DMG11, DMG13, DMG25, DMG26, DMG27, DMG28 and DMG29 were subsampled.

The samples were oven-dried at 40°C and then impregnated with polyester resin diluted with acetone. The impregnated blocks were cut in thin slabs with a rock saw. The final processing was conducted at the Spectrum Petrographics, Inc. (Oregon, USA), where in total 180 large-format thin sections (51x75mm) of 30 microns' thickness were prepared. The thin sections were studied under the petrographic microscope at magnifications ranging from 50 to 400x. The description of thin sections was based on the thin section description guidelines of Bullock *et al.* (1985), Courty *et al.* (1989) and Stoops (2003).

4.2.3. Chronology

^{14}C samples were extracted from different layers and trenches, to cover a wide range of spatial and temporal spectra. In total 222 samples were collected, and were evaluated by significance and quality to prioritize the dating process. 14 final samples were selected for AMS dating, which was conducted at Ångström Laboratory of the Uppsala Universitet, in Sweden. 4 samples were selected from the off-site section (2 from microfacies SM4.1 (Ua-43102, Ua-43103) and 2 from SM5.4. (Ua-43093, Ua-43097). In the mound, 2 samples were selected from microfacies SM4 (Ua-43106, Ua-43104), 1 from microfacies SM5 (Ua-43105), 1 from microfacies SM10 (Ua-43099) and SM7 from microfacies SM11 (Ua-43094, Ua-43095, Ua-43096, Ua-43098, Ua-43101, Ua-43100). Priority was therefore given to the upper anthropogenic layers of the site, where the existing dating results have been considered thus far fragmentary (Karkanas *et. al.*, 2011). For the final chronostratigraphic reconstruction, the existing results from Karkanas *et al.* (2011) and Facorellis *et al.* (2014) were considered and were reassessed in accordance to the new stratigraphical results. All the data are calibrated and statistically processed using Oxcal and Calib software.

4.2.4. Laboratory sedimentological analysis

The samples for the laboratory analysis were extracted from DMG09, DMG11, DMG07 and DMG06, considered the deepest and most stratigraphically representative cores, with sampling intervals ranging from 0.05m to 0.3m; these intervals were dependent on the facies, which were recorded during macroscopic laboratory and field observations. In total 130 samples were analyzed in Laser Particle Sizer and Thermogravimetric Analyzer at the sedimentology Laboratory of the Vrije Universiteit in Amsterdam. Sedimentology analysis was rendered impossible in the archaeological site due to the high concentrations of charcoal and organic matter content of the sediments.

4.2.4.1. Grain size analysis

The grain size is the most fundamental property of sediment particles, affecting their entrainment, transport and deposition. Grain size analysis therefore provides important clues to the sediment provenance, transport history and depositional conditions (Blott and Pye, 2001). McLaren (1981) was the first who used spatial changes in three grain size parameters, i.e. mean, sorting, and skewness, to identify transport directions in modern environments. To facilitate graphical presentation and statistical manipulation of grain size frequency data, grade scale boundaries are further logarithmically transformed into phi (φ) values, using the expression $\varphi = -\log 2\ d$, where d is the grain diameter in millimeters (Blott and Pye, 2001). The parameters are used to describe a grain size distribution into three principal groups (a) the average size, (b) the spread (sorting) of the

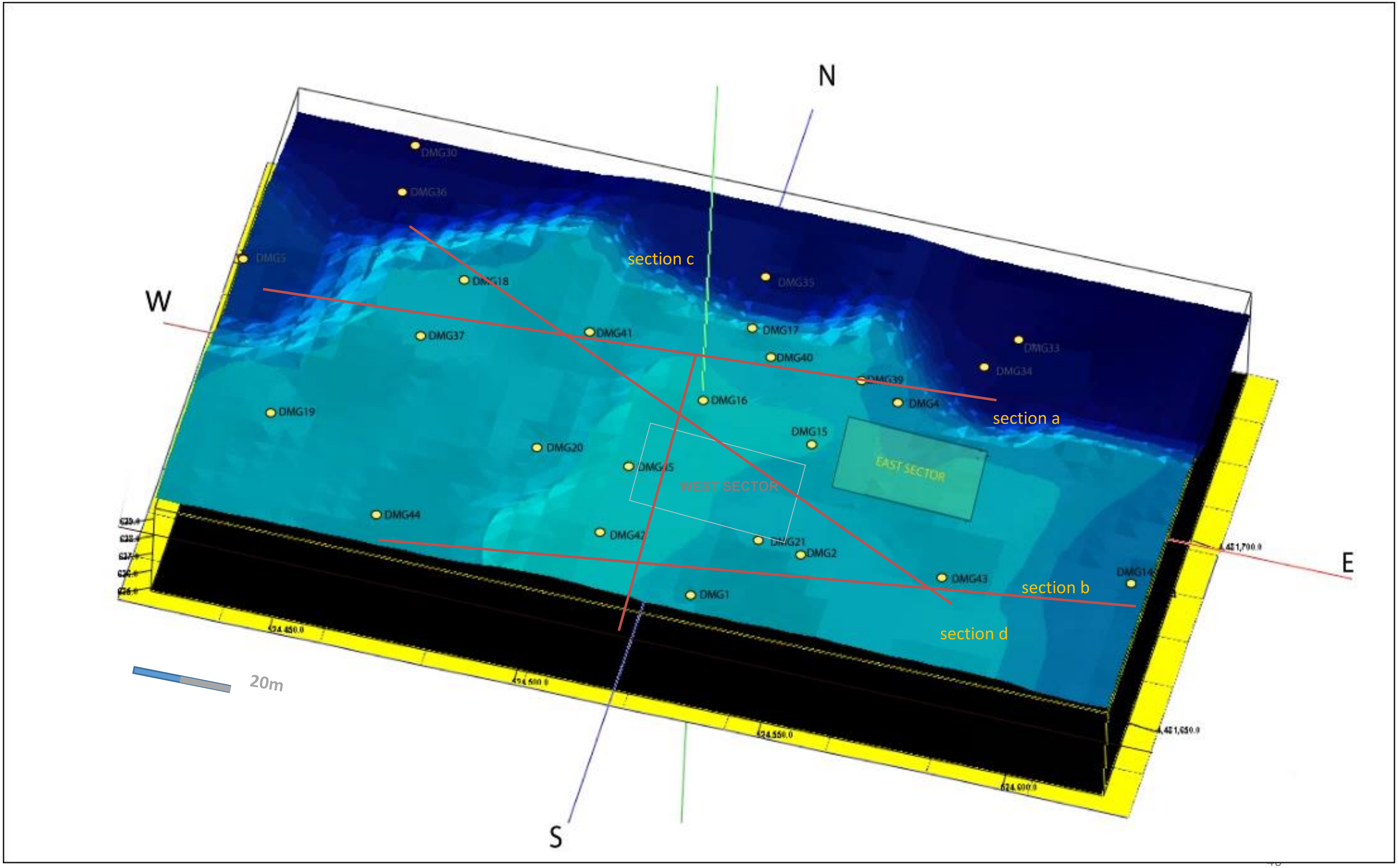

Figure 4.2: Map of the mound and the lake with the borehole locations (yellow dots) and the east sector in yellow. The west sector is visible in light gray. The relief of the mound is indicated in blue shades (dark blue for the lake and lighter for the higher elevations). The red lines indicate the cross-sections described in chapter 8

sizes around the average, (c) the symmetry or preferential spread (skewness) to one side of the average.

The analysis of grain size parameters contributes to the determination and interpretation of depositional processes. For the determination of the grain size group the Shepard's classification system was implemented (Shepard, 1954). The textural attributes of sediments, mean (Mz), standard deviation (SD), skewness (Ski) and kurtosis (KG) are often used to understand the history of sedimentation (Folk and Ward, 1957, Vakalas *et al*., 2004, Goswami and Ghosh, 2011). Furthermore, the correlation of the textural attributes and transport processes/depositional mechanisms has been established by exhaustive studies from many modern and ancient sedimentary environments referring to fluvial settings (Folk and Ward, 1957, Mycielska-Dowgiałło and Ludwikowska-Kędzia, 2011). This includes the mean grain size vs. standard deviation (Mz and Ski), the skewness vs the mean grain size (Ski and Mz), and the standard deviation vs the skewness (SD and Ski). Here, this method has been applied to evaluate its potential in the identification of lacustrine depositional processes. These relationships are presented in diagrams as fields of points.

The C-M diagram (Passega, 1957, 1964, 1977, Passega and Byramjee, 1969) is another method for assessing the results obtained from grain-size analyses, wherein the values of the first percentile (C) are plotted against the median (M) (probability scale). The C and M values may be presented in phi units and/or in millimeters. Thus, far, the so called Passega C-M diagram has been applied to the study of fluvial and coastal deposits, as both consist of different lithofacies, which can be 'translated' into depositional sub-environments with the help of the diagrams. In lacustrine sediments, the Passega diagram has been intermittently used (Vijayakumar *et al*., 2011, Sivasamandy and Ramesh 2014). In this study the C-M diagram has been implemented in conjunction to texture parameters, so as to supplement the macroscopic descriptions. According to Passega (1957, 1964) and Passega and Byramjee, (1969) the first percentile refers to the grain size that is representative of the maximum competence of the transporting medium. Based on the analysis of river and marine coastal deposits, Passega and Byramjee (1969) distinguished three basic limits, divided into units: rolling (units 1, 2, 3, 9), graded suspension (a term used to replace saltation, units 4, 5, 7, 8) and uniform suspension (units 8 and 6). Units 1 to 9 form the lower size limit of grains transported through rolling (with a contribution of suspension); units 4-8 characterize the maximum diameter of grains transported in 'graded suspension', i.e. mainly through saltation; and units 8 and 6 represent the limit for the maximum size of grains transported in homogeneous suspension, i.e. in the upper part of the water column.

4.2.4.2. Thermogravimetric analysis (TGA)

Thermogravimetric analysis (TGA) is an analytical technique used to determine a material's thermal stability and its fraction of volatile components by monitoring the weight change that occurs as a specimen is heated (Heiri *et al.,* 2001). For sedimentology, this method is used to measure the total organic matter and $CaCO_3$ content. A dry sample is heated to a temperature of 1000 °C in steps of about 10 °C per minute. At certain temperatures, specific characteristics are measured, starting with initial weight, moisture, organic matter, structural water (in clay minerals); at the highest temperatures calcium carbonate ($CaCO_3$) is measured. For this project the organic matter content and $CaCO_3$ parameters are considered, as valuable indicators of lake level fluctuations and depositional settings (see 3.2.2.3). The number of samples measured is the same with that for the grain size analysis (see 4.2.4.1.).

4.2.5. The 3D reconstruction model

4.2.5.1. Introduction

Nowadays, almost all archaeological excavations use the concept of excavation/stratigraphic units, loci, layers, or other terms employed by field archaeologists referring to a 3D volumetric component of archaeological remains/debris within a site under excavation (Losier, 2007). Nevertheless, surprisingly, most of them are still relying heavily on 2D representations of the excavation units for their analysis and interpretation, and consequently, publications. These 2D representations take the form of drawings showing excavation units in section/cut, normally superposed onto each other in a stratigraphic sequence. Vertical sections and their drawings in 2D are used as a primary source of recording the stratigraphic sequence and do not permit flexibility. Being able to model 3D facies in realistic 3D representations, at the same time as managing their relationships, would be an asset for field archaeologists because it would allow them to visualize the results in a more realistic manner. Displaying three-dimensional facies could be an important aid in understanding stratigraphic relationships and identifying potential patterning.

4.2.5.2. Methodology

For this study, a predictive model was used to integrate the stratigraphic data derived from the excavated sectors with the borehole cross sections and further extrapolate the results to the mound extent[1]. For this purpose, Rockworks 15 software was implemented, which has long been the standard software in the petroleum, environmental, geotechnical and mining industries for subsurface data visualization. Rockworks uses all the stratigraphic data to create a solid model of each stratigraphic unit. A degree of caution however needs to be taken over the use of interpolation methods. There has been a growing recognition of the influence of different interpolation methods on results (Kvamme, 1990, Chaplot *et al.*, 2006, Desmet, 2007). For this project the dense sampling and the detailed analysis of stratigraphic data allowed the evaluation of the interpolation results. Therefore, the closest point algorithm (known as the closest neighbor) has been considered as the most statistically accurate reconstruction tool for the facies distribution. This is the most basic solid modeling method, in which the value of a voxel node is set to be equal to the value of the nearest data point, regardless of its distance from the point or the value of its other neighbors (Cattani *et al.*, 2004). This method is useful when generating models, in which the values are not gradational. As a disadvantage, this algorithm produces a grid model with abrupt changes between grid nodes. For this reason, smoothing tool at Level 1 was used.

However, there are some errors of interpolation, especially if we want to build a cumulative solid model. Especially in cases of intersecting facies, the results are not always accurate. For the construction of the solid model therefore a manual option was selected to evaluate the interpolation results and control the facies boundaries. So, stratigraphic thickness grids were constructed for each unit using, as described above, the closest point algorithm, and the intersection of the facies was completed by using the append command. The visualization of all the stratigraphic units was conducted with APPEND command. For the final presentation of the site configuration in relation to the lake water fluctuations Illustrator Adobe software was implemented.

[1]Stratigraphic data were extracted from the excavated east sector, representing the most characteristic sequences. In total four columns (NW, NE, SW and SE) were extrapolated.